NAVY EXPERIMENTAL DIVING UNIT

TECHNICAL REPORT NO. 10-96

EVALUATION OF DIVING SYSTEM INTERNATIONAL (DSI) KMB-28B BANDMASK

D.L. JUNKER
R.W. MAZZONE

JUNE 1996

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
321 BULLFINCH ROAD
PANAMA CITY, FLORIDA 32407-7015

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Submitted:

D.L. JUNKER
MMCM(DV), USN
Unmanned Testing Officer

R.W. MAZZONE
LCDR, USN
Senior Projects Officer

Reviewed:

D. BAISS
CWO4, USN
Fleet Diving Projects Officer

M.E. KNAFELC
CAPT, MC, USN
Senior Medical Officer

J.R. CLARKE
GM-15
Scientific Director

J. NELSON
LCDR, USN
Executive Officer

Approved:

J.R. WILKINS III
CDR, USN
Commanding Officer

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Navy Experimental Diving Unit (NEDU) evaluated the DSI KMB-28B Bandmask as requested by COMNAVSEASYSCOM Code 00C. Unmanned testing was conducted to 198 fsw at a temperature of 40° F at RMV's of 22.5 to 90 $Lxmin^{-1}$. Manned testing was conducted in the NEDU test pool to evaluate form, fit and function. Additionally, manned dives were conducted to a depth of 190 fsw in the OSF by divers wearing hot water suits. Results of unmanned testing showed that the KMB-28B Bandmask has breathing performance characteristics which meet or exceed those of the MK 1 MOD 0 Bandmask. Additionally, no evidence of CO_2 pocketing or retention was observed. The KMB-28B Bandmask received very favorable ratings by all divers. In addition, the KMB-28B utilizes many of the same parts as the currently approved MK 21 MOD 1 diving helmet. NEDU strongly recommends that the KMB-28B be approved for Navy use.

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GLOSSARY

ANU	Authorized for Navy Use List (NAVSEAINST 10560.2 series)
fsw	Feet of Seawater, a unit of pressure. One fsw = 0.3063 msw.
J/L	Joules per liter, unit of measure for "Work of Breathing" normalized for tidal volume. One J/L = 1 kPa.
kPa	Kilopascals or Newton/m^2, unit of pressure. One kPa ~ 10.2 cmH_2O
msw	Meters of Sea Water. One msw = 3.2646 fsw.
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
psi	Pounds per Square Inch, an English measure of pressure. One psi = 6.895 kPa. 1 bar = 14.504 psi.
resistive effort	Formerly termed Work of Breathing (WOB). Properly, a volume averaged pressure determined by the average flow resistance of a breathing impediment and average minute ventilation. Units of kPa, or in a more cumbersome format, J/L.
RMV	Respiratory Minute Volume with units of $L \cdot min^{-1}$. In scientific publications, this is referred to as expired ventilation ($\dot{V}_E$).

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INTRODUCTION

During the 1995 Working Divers Conference, a request was made to identify a replacement for the MK 1 MOD 0 Bandmask. Subsequently, the Navy Experimental Diving Unit (NEDU) was tasked[1] to evaluate Full Face Masks for surface supplied diving, with specific instructions to find a bandmask which would fill the void created by the retirement of the USN MK 1 MOD 0 Bandmask.

FUNCTIONAL DESCRIPTION OF EQUIPMENT

In 1995, Diving Systems International, Inc. (DSI) began production of the KMB-28B, an injection molded plastic version of the KMB-18 (the bandmask version of the DSI Superlite 17 helmet). The KMB-28B Bandmask was specifically introduced as a low cost alternative to the KMB-18. The KMB-28B is virtually identical in form, fit, and function to that of the retired MK 1 MOD 0 Bandmask.

The DSI KMB-28B Bandmask is an open circuit, surface supplied full face mask. It has a neoprene hood and adjustable rubber spider to hold the mask in place. The mechanical systems are identical to the commercial off-the-shelf DSI Superlite 17B. Additionally, with only minor exceptions, they are also the same as the USN MK 21 MOD 1 Helmet.

TEST PROCEDURES

UNMANNED TESTING

General

Unmanned testing for resistive effort (formerly termed Work of Breathing) and CO_2 retention was conducted on three DSI KMB-28B masks (serial numbers 001, 002, 003)[2]. Each mask was test dove to 198 fsw. Breathing air was supplied to the masks via the Experimental Diving Facility (EDF) facility regulator maintained at 135 psig overbottom. This in turn supplied a 10 cubic foot volume tank and 300 foot long, 3/8" (9.5 mm) i.d. continuous length umbilical. The subject masks were attached to breathing mannequins and submerged in a fresh water bath maintained at 40° F $\pm$ 1.8° F (4.4° C). Data was collected in 1 ATA increments from the surface to 198 fsw (0 to 60 msw).

Breathing Simulator

Ventilation of the masks was accomplished using a computer controlled electro-mechanical breathing simulator (Battelle, Columbus, OH). Masks were ventilated at

RMV's of 22.5, 40.0, 62.5, 75.0 and 90 $L \cdot min^{-1}$. Testing was terminated if the inhalation or exhalation pressures exceeded 4 kPa, the working limit of our pressure transducers. Gas from the breathing machines was heated and humidified using a bubble chamber maintained at 30° C (± 1° C). Additionally, CO_2 was injected into the breathing gas at a rate of 1.3 $L \cdot min^{-1}$ in order to evaluate gas pocketing in the mask.

Data Acquisition

A PC 386DX computer systems equipped with National Instruments data acquisition system and National Instruments Lab Windows was used to process work of breathing data. CO_2 data as well as temperature and gas supply pressures was monitored utilizing a Macintosh IIci computer system. CO_2 levels were monitored using an Ametek CD3A CO_2 analyzer.

MANNED EVALUATION - TEST POOL PHASE

Seventeen manned dives were conducted in the NEDU 15 foot deep test pool for subjective evaluation of form, fit and function[3]. Test pool temperature was ambient (approximately 75° F). Each diver performed approximately 15 minutes of light to moderate work (50-75 watts) on a pedal ergometer. Upon completion of the work cycle, the divers were instructed to assume the positions of standing, 45° face down, 45° face up, prone, supine, head full up, head full down to evaluate ease of breathing and mask comfort. On completion of the dive, each subject completed a "Human Factors Evaluation Questionnaire" (Appendix A)

MANNED EVALUATION AT 190 FSW - OSF PHASE

General

Twelve manned dives were made in the NEDU Ocean Simulation Facility (OSF) to a depth of 190 fsw (57.9 MSW)[4]. Wet pot temperature was maintained at 40° F (4.4° C). All divers wore hot water suits, although the hats were not equipped with a hot water shroud.

The primary purpose of these 190 fsw bounce dives was to determine if the KMB-28B can support a moderate to hard working diver at depth. Divers breathing air was supplied via the OSF facility tracking regulator set at 135 psig attached to a 300 foot long, 3/8" i.d. continuous length umbilical. Each diver engaged in incrementally increasing work cycles on a pedal ergometer (75 watt maximum) and responded to a Performance Evaluation Questionnaire concerning their perceived breathing resistance (dypsnea). Upon completion of the dive, each subject completed a Human Factors

Evaluation Questionnaire (Appendix A), identical to that used during the manned test pool phase.

Data Acquisition

The NEDU data acquisition system, consisting of National Instruments Data Acquisition boards, Macintosh Quadra microcomputers, and LabView (National Instruments) was used to collect data. NEDU Medical personnel instrumented both KMB-28Bs in a similar fashion to record end-tidal carbon dioxide ($P_{ET}CO_2$) levels, and helmet ΔP. Both test-divers were monitored simultaneously.

$P_{ET}CO_2$ was monitored by Extrel NGA 2000 mass spectrometer. The gas sample line was located in the test-diver's exhaled breath stream. A microvalve placed in the sample line allowed fine adjustment of the sample gas flow rate. Each diver's $P_{ET}CO_2$ was logged at 80 Hz. However, due to the configuration of the mass spectrometer control software, data were sent from the mass spectrometer to the data acquisition computer at approximately 20 Hz.

Helmet ΔP was monitored with a Validyne (DP-15, DP-9, or equivalent) pressure transducer with a ± 80 cm H_2O (7.8 kPa) diaphragm. The positive side of the transducer monitored pressure in the oronasal cavity; the negative side referenced the diver's suprasternal notch. Oronasal pressures were sampled and logged at 80 Hz.

Cycle ergometers (W.E. Collins) staged on a platform within the wet pot provided measured work loads for the two working divers. The depth from "C" chamber digigage plus six feet was used as the actual depth of the divers on the ergometers.

Data reduction and analyses were performed on Intel Pentium personal computers running Windows for Workgroups Ver. 3.1 (Microsoft Corporation, Redmond, WA). WOBVB, a locally produced Visual Basic 3.0 (Microsoft Corp.) program selected appropriate data points for analysis. S-PLUS for Windows Version 3.3 (StatSci, Seattle, WA) was used for statistical analyses and graphs.

TEST RESULTS

UNMANNED TESTING

Resistive efforts (formerly termed WOB) are summarized in Figure 1. Note that resistive effort met the performance goal for category II UBA's for RMV's up to 40 $L{\cdot}min^{-1}$. At an RMV of 62.5 $L{\cdot}min^{-1}$ (relatively hard working diver), the resistive effort for the KMB-28B met the performance goal at 66 fsw, but not at deeper test depths.

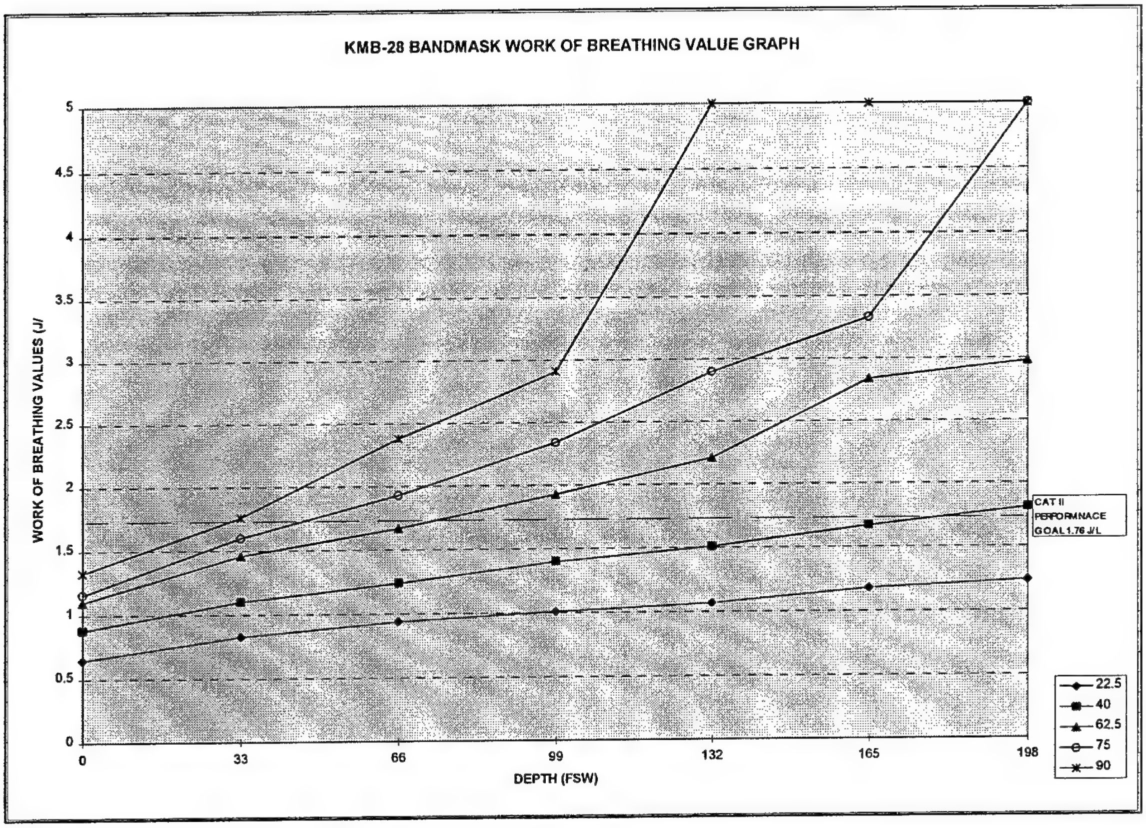

Figure 1. Resistive effort of the KMB-28B.

Figure 2 shows a comparison of the resistive effort of the USN MK 1 MOD 0 and DSI KMB-28B. These results are remarkably similar to that of recent USN MK 21 MOD 1 trials and virtually identical to that of the original USN MK 1 MOD 0 data collected in 1978[5].

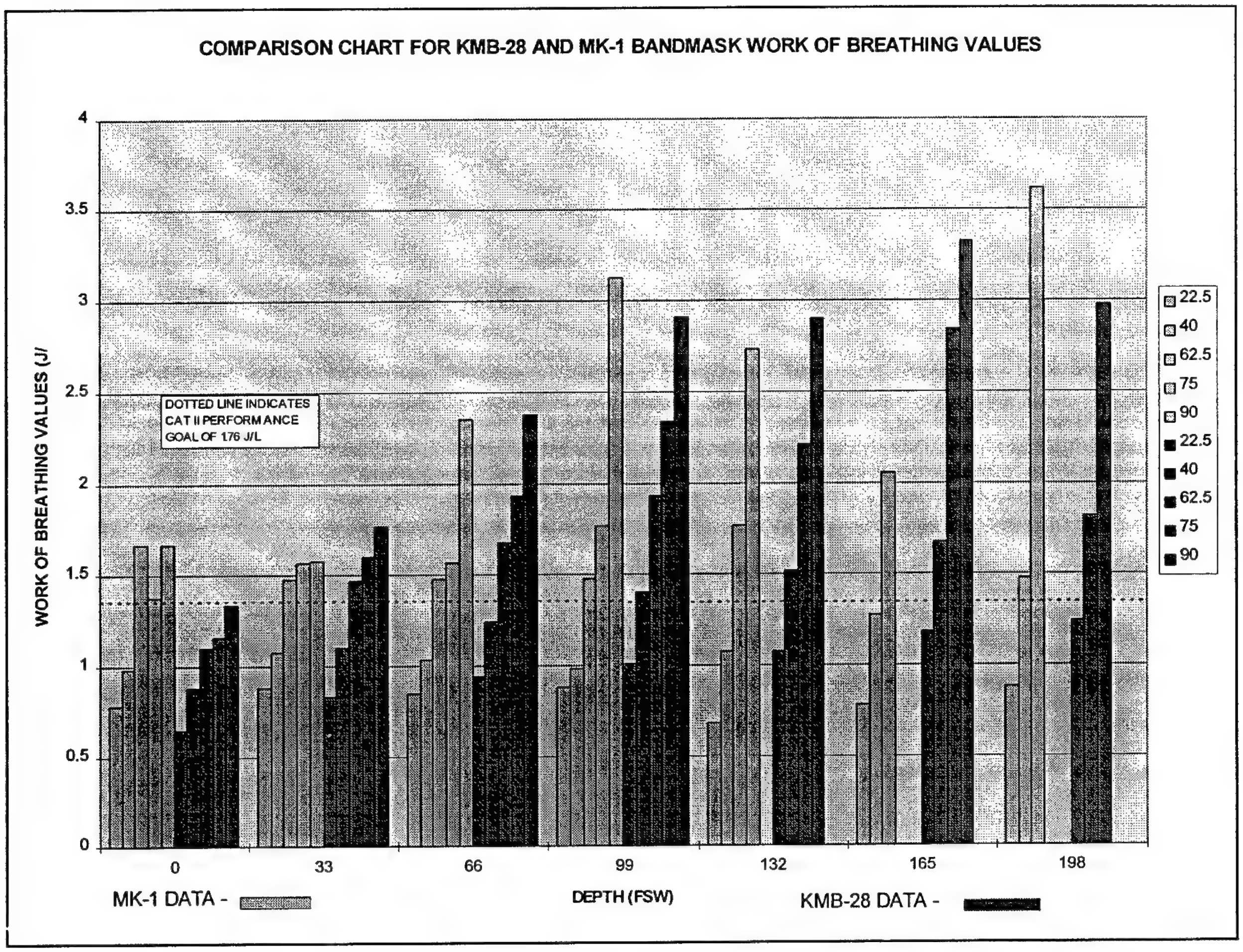

Figure 2. Resistive effort of the MK 1 compared with the KMB-28B.

HUMAN FACTORS EVALUATION: TEST POOL AND OSF

The KMB-28B Bandmask received favorable ratings on the human factors evaluation. Significant comments included the following:

1. Subjective breathing performance at light to moderate work loads was rated GOOD to EXCELLENT by all divers.

2. All divers except one rated visibility of the mask GOOD to EXCELLENT.

3. Approximately 25% of the divers complained of the mask pulling to the right side (side block and EGS connection side). This complaint has been noted for years, originally by MK 1 divers. It can be easily remedied by supporting the umbilical and EGS whip properly.

Manned Results: OSF

In the manned study, 12 Navy divers participated as test-divers. Each diver made one dive.

$P_{ET}CO_2$ values were taken as the peak values from reasonable breath cycle tracings. Since the sampling time was sufficiently short, the average of $P_{ET}CO_2$ values for any given condition was used in the analyses to decrease the breath-to-breath variability in $P_{ET}CO_2$. On the average, 9 reasonable breath cycles were logged per condition per dive.

Using simple linear regression, we found no statistically significant association between the average ΔP and the watt rate (considered as a ratio or nominal value) or the average breaths per minute. Likewise, we found no statistically significant association between the average $P_{ET}CO_2$ and the watt rate (considered as a ratio or nominal value), the average breaths per minute, or the average Δ P.

Composite Descriptive Statistics

Work Rate [watts]	Composite Helmet Δ P [cm H_2O ± SEM]	Composite Max End Tidal CO_2 [mmHg ± SEM]	Composite Respiratory Rate [min^{-1} ± SEM]
35	30.5 ± 3.3	42.4 ± 5.3	17.4 ± 1.6
50	29.4 ± 2.0	37.5 ± 5.3	21.5 ± 2.0
75	36.6 ± 2.6	31.02 ± 7.4	20.9 +- 2.1

At first glance, the above ΔPs appear puzzling. We would expect the mean values to increase with work rate since diver ventilation increases with work rate. However, as seen in Figure 3, the pooled ΔP data was highly variable. Median values (thick horizontal lines) did trend upward with work rate, but the diver-to-diver and run-to-run variability was too large to demonstrate the expected increase in mean values with work rate.

An explanation of the symbols used in Figures 3 and 4 is found in reference (6), the manual accompanying our S-Plus statistical software. In referring to the three rectangular vertical boxes in each figure, the "horizontal line in the interior of the box is located at the median of the data. This estimates the center of the distribution for the

data. The height of the box is equal to the interquartile distance, or IQD, which is the difference between the third quartile of the data and the first quartile. The IQD indicates the spread or width of the distribution for the data. The whiskers (the dotted lines extending from the top and bottom of the box) extend to the extreme values of the data or a distance 1.5 X IQD from the center, whichever is less. For data having a Gaussian distribution, approximately 99.3% of the data falls inside the whiskers. Data points which fall outside the whiskers may be outliers, and so they are indicated by horizontal lines."

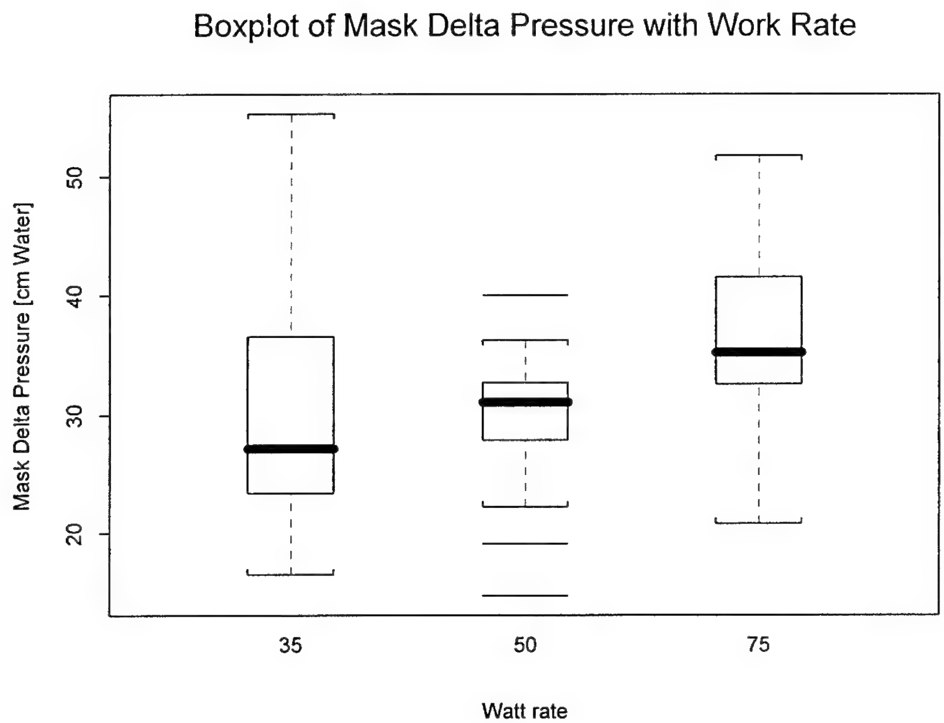

Figure 3. ΔP vs. Work Rate.

The KMB-28B also received very favorable ratings by all divers even at 190 fsw. Inhalation and exhalation breathing resistance was rated as slight and all divers expressed a high degree of confidence in the rig in an emergency.

The values for ΔP and end-tidal CO_2 are well within acceptable limits. Hence, the KMB-28B will support hard working divers to depths of 190 fsw.

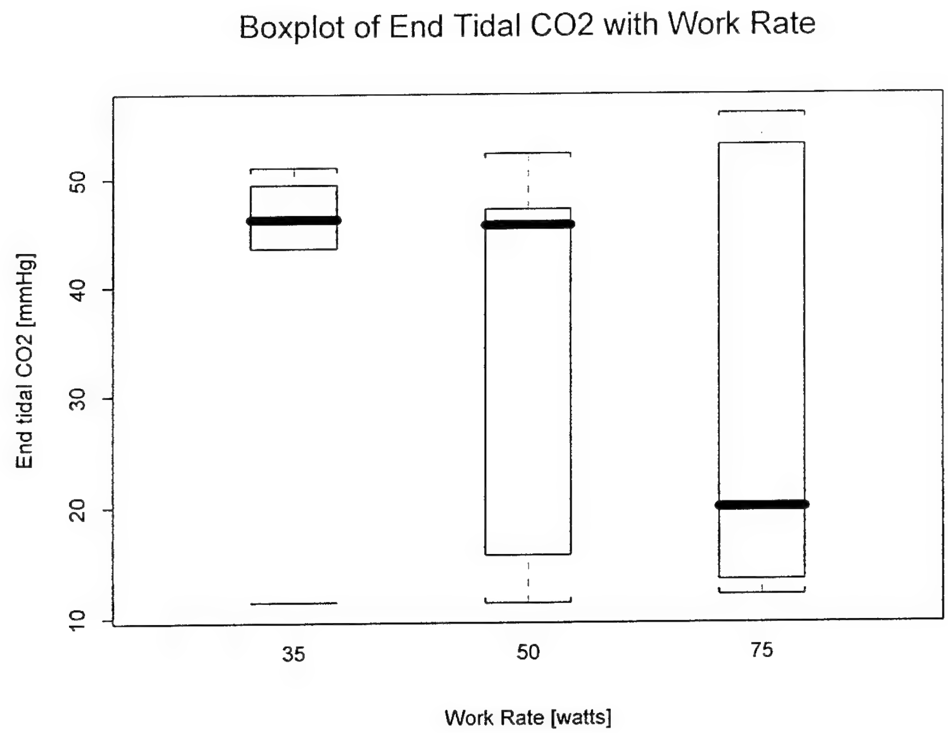

Figure 4. End Tidal CO_2 vs. Work Rate.

Interface with the MK 21 MOD 1

The KMB-28B utilizes many of the same parts as the currently authorized MK 21 MOD 1 with the exception of the Regulator Body, p/n 545-080 (MK 21), p/n 545-022 (KMB-28B); Face Port, p/n 520-004 (MK 21), p/n 520-128 (KMB-28B); Mask, Oral/Nasal, p/n 510-548 (MK 21), p/n 510-540 (KMB-28B); Whisker, Rubber, p/n 510-555 (MK 21), p/n 510-554 (KMB-28B), Microphone, p/n 515-010 (MK 21), p/n 515-009 (KMB-28B). The KMB-28B side block assembly is identical to that used on the MK 21.

CONCLUSIONS AND RECOMMENDATIONS

The DSI KMB-28B Bandmask meets the NEDU standards for resistive effort (formerly termed Work of Breathing) down to a depth of 66 fsw, thereby covering the ship's husbandry depth range, when supplied with an overbottom pressure of 135 psig and 3/8" i.d. 300 foot long continuous length umbilical. At deeper depths, resistive effort matches that of the MK 1. Because this mask is mechanically identical to the commercial off-the-shelf Superlite 17B and with only minor exceptions, the same as the USN MK 21 MOD 1, the superior performance results obtained here are not unexpected.

In general, the DSI KMB-28B Bandmask is well built, easy to use and maintain and provides superior performance for the working diver, even under demanding conditions. Therefore, it is a suitable alternative for the MK 1 Bandmask for those diving lockers desiring the capability.

NEDU recommends that the DSI KMB-28B Bandmask be approved for Navy use.

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REFERENCES

1. Naval Sea Systems Command, *Alternative Full Face Mask (FFM) for SCUBA and Surface Supplied Diving*, NAVSEA Task 96-011, 26 January 1996

2. D.L. Junker and J.L. King, *Unmanned Evaluation of the Diving Systems International KMB-28 Bandmask*, NEDU Standard TP 96-05, Navy Experimental Diving Unit, March 1996, (Limited Distribution)

3. D.L. Junker and J.L. King, *Manned Test Pool Evaluation of Diving Systems International KMB-28B Bandmask*, NEDU Standard TP 96-08, Navy Experimental Diving Unit, March 1996, (Limited Distribution)

4. D.L. Junker, J.L. King and D. Baiss, *Evaluation of the Diving Systems International KMB-28B Bandmask*, NEDU Protocol 96/14, Navy Experimental Diving Unit, May 1996, (Limited Distribution)

5. J.R. Middleton and J.I. Brady, Jr., *Part I, Unmanned Evaluation of the USN MK 1 MOD 0 Mask and Umbilical and Emergency Modes, Part 2, Manned Human Engineering Evaluation of the USN MK 1 MOD 0 Mask and Tethered SCUBA Configuration*, NEDU TR 8-78, Navy Experimental Diving Unit, May 1978, (Unlimited Distribution)

6. *S-Plus Version 3.3 for Windows User's Manual, Statistical Sciences*, Seattle: StatSci, a division of MathSoft, Inc., p 4-51,52, 1995.

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APPENDIX A

HUMAN FACTORS EVALUATION QUESTIONNAIRE
DIVING SYSTEMS INTERNATIONAL KMB-28B BANDMASK

Name of diver: ______________________ Date of dive: ____________

Number of dives in past 3 years using full face mask, e.g., MK 20? __________

Dive profile: Depth(fsw)_______ Duration (min)_______ Water Temp(°F)_______

Brief description of dive ____

____

Describe dress used for dive ____

How was rig used during the dive?

Open circuit only ____ Closed circuit only ____ Open and closed circuit ____

RATING SYSTEM:

1=extremely poor	4=adequate
2=poor	5=good
3=not quite adequate	6=excellent

EASE OF DON AND DOFF:

1. How would you rate the ease of getting the harness over your head with the mask in place? ... ____
2. How would you rate the ease of tightening the straps? .... ____
3. How would you rate the ease of loosening the straps and doffing the mask?.......................... ____

OVERALL COMFORT OF MASK:

4. How would you rate the visibility provided by the mask?... ____
5. Were there any especially distracting blind spots/visibility problems (yes/no)?......................... ____

If yes, describe: ____

6. How would you rate the ability of the faceplate to remain unfogged?.. ____
7. How would you rate the overall comfort of the mask as it fit your face?..................................... ____
8. How would you rate the ease of preventing gas leaks around the face seal?.............................. ____
9. How would you rate the mask's comfort in terms of overall buoyancy? .... ____
10. How would you rate the noise level of the mask?... ____
11. How would you rate chattering of mask?.. ____

12. List specific points of face/mask contact that were uncomfortable. ______________________

____

13. If there was any discomfort wearing the mask, how long were you wearing the mask before the discomfort became apparent? ______________________________

14. What specific activities can you identify that made the mask especially uncomfortable?____

RATE THE FOLLOWING WORK OF BREATHING PARAMETERS:

	inhalation	exhalation
a. Standing upright		
b. At a 45° face up position		
c. At a 45° face down position		
d. In the head down position		
e. Prone position		
f. Supine position		
g. Overall rating		

USE AND OPERATION OF MASK:

15. How would you rate the ease of breathing the mask while at rest?.................................. .... ___
16. How would you rate the ease of breathing the mask at moderate work levels?................ .... ___
17. How would you rate the ease of breathing the mask at heavy work levels? .... ___
18. How would you rate the ability of the faceplate to remain unfogged?.............................. .... ___
19. How would you rate the accessibility and operation of the nose clearing device? .... ___
20. How would you rate the ease of clearing the mask after it was flooded?......................... .... ___

Please provide any additional comments about the mask that you think are important, including suggestions you feel would enhance its performance and safety: ________________________

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